RESEARCH DEPARTMENT

# Digital methods in television

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RESEARCH DEPARTMENT

# DIGITAL METHODS IN TELEVISION

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# DIGITAL METHODS IN TELEVISION

SUMMARY

*This report indicates some of the advantages to be gained by converting television waveforms to trains of binary digits before signal processing operations such as standards conversion are carried out. These operations could then be effected by digital storage and logic circuits, the main advantages being reliability and freedom from distortion.*

*A brief description is given of possible methods of performing video/digital and digital/video conversion and the ways in which various signal processing operations could be carried out using digital signals are discussed.*

*The report concludes that the advances in digital techniques in other fields will soon reach the point where the speed and capacity required for television applications are attained. There will be problems in applying these techniques to television and it is these aspects that Research Department should investigate.*

## 1. INTRODUCTION

Throughout industry there is a growing tendency to eliminate routine tasks by the use of more sophisticated equipment, advance in this direction being accelerated by a continuous improvement in the reliability of electronic devices together with a reduction in their cost. These advances have arisen partly from the introduction of the transistor and the integrated circuit, both of which offer a considerable improvement in reliability and a reduction in cost, and partly from the growing use of digital methods. These two avenues of development are in fact closely allied because integrated circuits are particularly well suited to logical or digital processes in which signals are characterized by one of two possible states.

Since broadcasting, and particularly television, is based entirely on electronic devices, it might be expected to be in the forefront of the advance towards automatic methods and the elimination of routine work, but in fact broadcasting seems rather backward in this respect. Engineers, who must be sufficiently well-qualified to recognize and deal with difficult problems, spend far too much of their time performing menial tasks - for example, setting up equipment; this work demands unremitting care if the quality of the transmitted pictures is to be maintained.

The ideal to be aimed at is the elimination of routine adjustment by introducing equipment which either performs perfectly, or is regarded as unusable and in need of repair. (Some adjustments would still have to be made to match the scene to the limitations of the medium but the operators doing this would be exercising artistic rather than engineering judgement.)

The best method known for simultaneously obtaining high accuracy and high reliability is to use a binary digital representation of the information to be handled. Whereas an accuracy of one per cent is adequate for most television purposes, a typical digital computer has an accuracy of one part in $10^{11}$ or more, and its reliability is such that the occurrence of an error in a single digit among perhaps $10^{11}$ digits handled in a single day would be regarded as a breakdown. Computers are rapidly becoming faster and cheaper.

At present, television signals convey information about the brightness of each picture point in the scene in analogue form; in other words, brightness is represented by a continuously-variable physical quantity; this quantity is usually a voltage or a current but it may be the frequency of an alternating quantity, as in magnetic recording. The first step in the application of digital methods would be to sample a television signal at a sufficiently high frequency, and to represent the value corresponding to each sample by an integer expressed in binary form; this process will be termed video/digital conversion. It is a special case of analogue/digital conversion. Subsequent handling and processing of

the signal would then take place by performing calculations on the series of numbers as in a digital computer. The numbers would then have to be converted back into a video signal, a process which will be termed digital/video conversion.

In order to avoid impairment of the picture by moiré patterns, sampling must take place at a frequency higher than twice the upper limit of the video band, i.e. more than 11 MHz for British 625-line television. In practice it is desirable to employ a sampling frequency somewhat higher than this to allow for the imperfections of filters, so that a sampling frequency of about 13 MHz would be used in practice.

If each sample of the video signal is represented by $n$ binary digits (or 'bits'), then the digital system can represent up to $2^n$ different video levels. For example, if 3 bits are used, then the digital system can represent 8 different video levels, indicated by the eight binary numbers 000, 001, 010, 011, 100, 101, 110 and 111.

Since the signal is effectively 'quantized' by digital representation, it is necessary to use a sufficient number of levels to avoid spurious contours, which are most likely to be visible in large areas of almost uniform brightness.

Photographs of television pictures which have been quantized into 16 and 64 levels respectively are shown in Figs. 1 and 2. It can be seen that, for the pictures used, contours are clearly visible with 16 levels but are difficult to detect with 64 levels.

Since all the operations that would be carried out by digital means could also be performed by existing techniques, although less well and less reliably, it is considered essential that no defects attributable to sampling or quantizing should be perceptible at all. Experiments have shown that with 64 levels, contours are just visible as a kind of 'creeping stain' on some still pictures, particularly when slow variations of brightness occur. This means that at least 128, and possibly 256, levels would be necessary; in the latter case each sample would be represented by 8 bits.

It is possible to effect some economy in the number of bits by processes which effectively provide more levels in plain areas than in fine detail. These techniques may prove useful but it is conceivable they could conflict with certain processes that might be performed upon the digital signal. On the other hand, it might prove desirable to work with more than 8 bits per sample during certain processes in order to avoid rounding-off errors. This procedure would be equivalent to the usual computing practice of carrying out arithmetic processes to more decimal places than will ultimately be required and rounding-off only at the end.

A number of alternative binary codes are available, the simplest being conventional binary numbers. However, conversion between one code and another is a very easy matter and could be performed whenever it proved desirable.

The separate digits (say 8 for 256 levels) of the binary number representing each sample may be carried in 8 separate channels so that each channel only has to handle pulses at 13 MHz; such a means of transmission is known as parallel transmission and would undoubtedly be employed within most processing equipment. However, for transmission of the signals along circuits having sufficient bandwidth, the 8 digits could be sent in sequence; this is known as serial transmission. The circuit would then have to carry pulses at about 100 MHz, and would require a bandwidth in excess of 50 MHz; this form of transmission is referred to as pulse-code modulation (p.c.m.).

An important restriction of the use of digital techniques which must apply for many years to come is imposed by the fact that analogue devices employing electron beams are used to form and display television signals. If the processing and transmission of signals in digital form became widespread, these electron-beam devices, such as camera tubes and cathode-ray tubes, would stand out more prominently than they do now as the most unreliable parts of the system. The situation would then be comparable with that obtaining in computer installations where it is the peripheral equipment (e.g. paper-tape readers and punches, magnetic-tape equipment, etc.) that breaks down most frequently and requires most maintenance. However, more sophisticated methods of compensation and control which would be facilitated by the adoption of digital processing could do much to mitigate the vagaries of electron-beam devices.

The application of digital techniques to television is by no means new[1] although nothing is known of any work directed to the introduction of digital methods for television-signal processing. One application that has been exploited in the U.S.A. is to enable a television signal to be carried by a group of modified telephone circuits[2], parallel transmission being used. Each circuit can be arranged to provide sufficient bandwidth for conventional television signals but then has a signal/noise ratio which is adequate only for binary signals. Much work has also been directed to the use of pulse-code modulation in order to exploit links having a very wide bandwidth - of the order of 100 MHz - and a poor signal/noise ratio. Bell Laboratories appear to be the leaders in this field[3], but others have also carried out a considerable amount of work on the subject[4].

*Fig. 1 - Television picture quantized into 16 brightness levels*

*Fig. 2 - Television picture quantized into 64 brightness levels*

It is noteworthy that pulse-code modulation is believed to be the system destined to carry a high proportion of telephone traffic both on trunk routes and within telephone exchanges. Many engineers believe that p.c.m. will eventually displace carrier systems but the transition from one system to another is clearly very difficult. Work is at present going on with a view to developing a hybrid system as an interim measure.

Although the foregoing discussion has been simplified by restricting attention to monochrome television, it is clear that long-term investigations such as this should be concerned only with colour. Colour information can be incorporated in digital signals either by coding red, green, blue (and possibly separate-luminance) signals separately in digital form, or by coding luminance and colour-difference signals (the latter would require fewer samples) separately, or by sampling a composite colour signal. The form chosen would depend upon the application; conversion from one form to another (this could amount to colour coding, decoding or transcoding) could, like other processes, be performed digitally.

## 2. CONVERSION BETWEEN VIDEO AND DIGITAL SIGNALS

### 2.1. Video/Digital Conversion

This is the more difficult of the two directions of conversion because a separate 'yes or no' decision must be made to determine the value of each bit. The most usual approach is indicated schematically in Fig. 3, which has been simplified by supposing that the signal is quantized into only 16 levels so that only 4 bits are required; these will be assumed to represent $V/2$, $V/4$, $V/8$ and $V/16$ respectively where $V$ is the peak magnitude of the signal. The first step is to sample the continuously-varying video signal and to compare the amplitude of each sample with $V/2$, the value of the most significant bit; if the sample is greater than $V/2$, then $V/2$ is subtracted from it and a note is made that the most significant bit is 1. Otherwise the most significant bit is 0 and the sample is passed on unchanged to the next stage. There it is compared with $V/4$; if it is greater than this, $V/4$ is subtracted from it and a note is made that the second bit is 1. Otherwise the second bit is 0 and the signal is passed on to the next stage unchanged. This process is repeated to determine successive bits in order of diminishing significance.

Since all these operations have to be performed in sequence, it is not at present practicable to perform them all in the interval (about 80 ns) between successive samples. A system analogous to the 'line' system used in mass production must therefore be employed. As soon as the most significant bit has been dealt with the signal is passed on to the next station on the digital 'production line' and a fresh sample enters the first station. In fact it might be necessary to use two intervals of 80 ns to determine each bit; with 8-bit representation there could be 16 samples in the production line simultaneously. Pulses representing the bits that have been determined would have to take a parallel route having the appropriate delay in order to ensure that all the bits for each sample appear simultaneously.

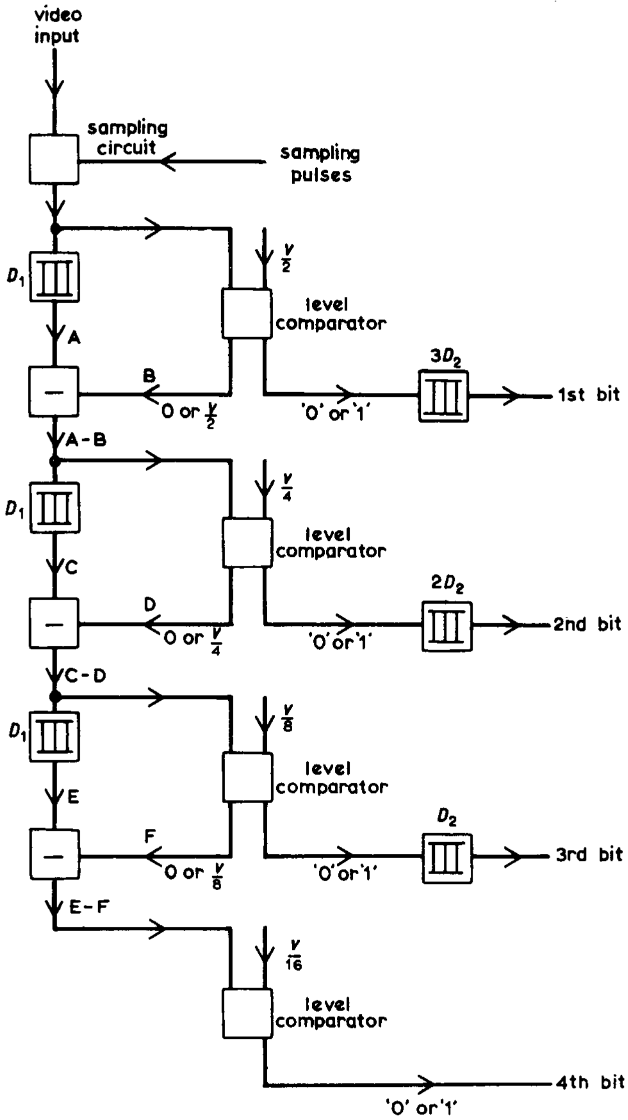


*Fig. 3 - Block diagram of video/digital converter*

$D_1$ = delay in level comparator
$D_2$ = delay in one stage (i.e. $D_1$ + delay in subtractor)

If the video input signal to the type of converter described above were a sawtooth waveform as shown in Fig. 4(*a*), then the value of the first three binary digits could be indicated by pulse trains such as those shown in Figs. 4(*b*), (*c*) and (*d*). Fig. 4(e) shows the signal obtained when these

three pulse trains are converted back into video form (see next section).

An experimental video/digital converter based on the outline given above has been developed by Research Department; it will form the subject of a separate report.

Up to this point it has been tacitly assumed that a linear representation of the incoming video signal is to be represented by a series of binary numbers. In fact it would be possible for the binary numbers to represent some function of the amplitude of the incoming video signal. For example, if the incoming signal were linear (rather than gamma corrected) a video/digital converter could be devised to give a binary representation of a gamma-corrected signal directly. In general, however, this could not be done with the kind of video/digital converter described above.

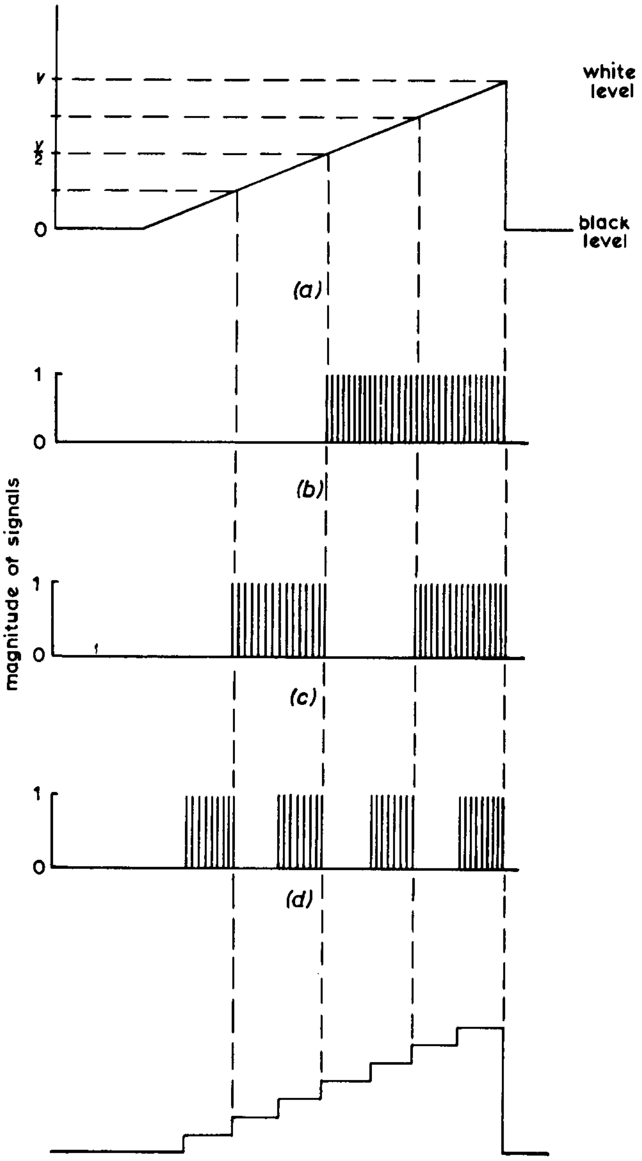


*Fig. 4 - Signals obtained in video/digital conversion from sawtooth video signal*

(a) Original video signal
(b) Pulse train indicating most significant bit
(c) Pulse train indicating second most significant bit
(d) Pulse train indicating third most significant bit
(e) Video signal obtained from the 3 digital pulse trains

Conversion to a code representing in binary form the logarithm of the video-signal amplitude could be effected by a converter similar to that described above but which attenuates or amplifies the analogue signal at each stage instead of adding to it or subtracting from it.

The digital output of such a logarithmic converter gives the value of the index '$m$' in the equation below, in which $V$ represents the magnitude of the incoming video signal,

$$V = Ka^m$$

where '$K$' and '$a$' are constants.

If '$n$' bits are used for '$m$', then quantum levels occur at $V = K, Ka^1, Ka^2, Ka^3 \ldots Ka^{2n-1}$. (Expressing $m$ as a binary number with $n = 3$, quantum levels occur at $V = Ka^{000}, Ka^{001}, Ka^{010} \ldots Ka^{111}$.)

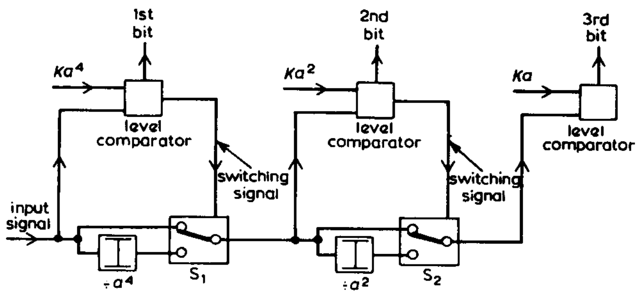


*Fig. 5 - Logarithmic video/digital converter*

One possible procedure for determining $m$ (with $n = 3$) is illustrated in Fig. 5. The theory will not be explained here but the method of operation is as follows:-

If $V > a^{2^{(n-1)}}$, divide by $a^{2^{(n-1)}}$ and record the most significant bit as 1; otherwise record the most significant bit as 0 and apply signal $V$ directly to next stage of converter.

If $V$ (as modified) $> a^{2^{(n-2)}}$, divide by $a^{2^{(n-2)}}$ and record second bit as 1; otherwise, record second bit as 0.

Lower order bits are determined in a similar manner.

An alternative converter which could give the binary representation of any function of the incoming signal could contain a separate level discriminator for each quantum level. For example, if 8 bits were to be used to represent 256 levels then 256 level discriminators would be required.

### 2.2. Digital/Video Conversion

The basic principles of obtaining a video signal from a digital signal of the form obtained from the video/digital converter shown in Fig. 3 may be explained as follows[5].

A pulse representing the most significant bit is given a weighting of 1/2, a pulse representing the second bit is given a weighting of 1/4, a pulse representing the third bit is given a weighting of 1/8 and so on. The weighted pulse trains thus obtained from the input bit-pulse trains are then added together and the resulting signal is passed through a low-pass filter which removes spurious components introduced by the sampling process. The output of this filter is the required analogue signal (see Fig. 4(e)). This video signal will be quantized into $2^n$ levels where '$n$' is the number of bits per sample.

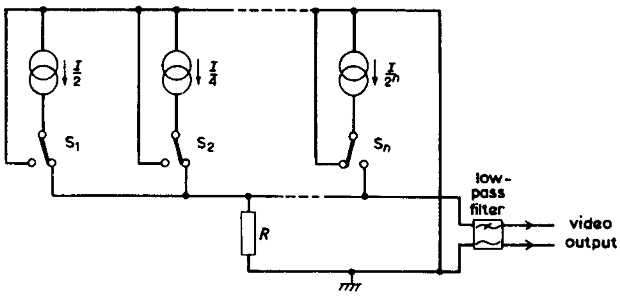


*Fig. 6 - Digital/video converter*

One method of weighting the bit pulses is illustrated in Fig. 6. The switches $S_1$, $S_2$ . . . . $S_n$ are operated simultaneously by the bit pulses describing any given sample of the video signal, $S_1$ being operated by the pulses representing the most significant digit, $S_2$ by the pulses representing the second most significant digit and so on.

The digital output of the logarithmic converter shown in Fig. 5 could be converted back into a linear representation of the original video signal by the method illustrated in Fig. 7. The switches $S_1$, $S_2$ and $S_3$ are operated simultaneously by the bit pulses describing any given sample. $S_1$, $S_2$ and $S_3$ are operated by the most, second most and least significant digits respectively; the mode of operation is such that the attenuators are by-passed when the digit 1 is present.

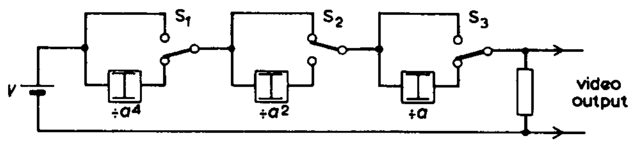


*Fig. 7 - Anti-logarithmic digital/video converter*

### 2.3. Other Forms of P.C.M. Suitable for Television Signals

Standard p.c.m. is not the only manner in which video information can be transmitted in a digital manner. Other possible forms of p.c.m. include delta modulation[6] and differential p.c.m.[7].

With both these forms of coding, the coded signal conveys information about the difference between the actual magnitude of the analogue signal and an estimate of its magnitude based on its past. The simplest estimate for this purpose is the actual magnitude of the previous sample; each group of digits then describes the difference between successive samples.

In delta modulation the sampling rate is many times that of the highest-frequency component in the analogue signal and only one digit is transmitted per sample; a 1 indicates an increase in magnitude of the signal and a 0 indicates a decrease.

In differential p.c.m., several digits are used per sample and the sampling rate is usually the same as for standard p.c.m. In order for this system to have any advantage over standard p.c.m., it is necessary to use a non-linear coding system so that the difference in voltage between quantum levels increases as the magnitude of the difference signal between actual and estimated signals increases.

A block diagram of a video/digital converter suitable for converting for both types of coding is shown in Fig. 8. As shown in this diagram the estimate of the signal magnitude is derived from the digital output of the converter.

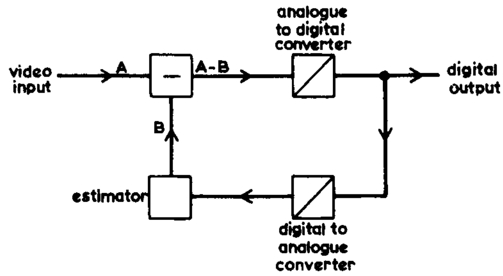


*Fig. 8 - Video/digital converter for delta modulation or differential p.c.m.*

With both these systems, it is possible to reduce the visibility of unwanted contours (for a given bit rate) compared with that obtained with standard p.c.m., but this advantage is obtained at the expense of less accurate representation of high-frequency detail. From these theoretical considerations, it would appear that delta modulation and differential p.c.m. are more suitable than standard p.c.m. for monochrome television signals, but for

colour television signals, which require very accurate processing of the high-frequency colour subcarrier, it would appear that standard p.c.m. is the most suitable system.

On the other hand, both delta modulation and differential p.c.m. have practical disadvantages in that the conversion of television signals into these forms requires considerably faster-acting circuits than are required for conversion to standard p.c.m.

## 3. THE PROCESSING OF DIGITAL SIGNALS

### 3.1. General

In this section consideration is given firstly to basic processes which may be regarded as 'building bricks' and then to more complex operations in which a number of basic processes are combined.

It is natural to ask whether a general-purpose digital computer might be employed - at least experimentally - for processing video signals; unfortunately, the fastest machines available at present are far from meeting the requirements. The fastest general-purpose computers can perform arithmetic operations at about $10^6$ operations (for example additions or multiplications) per second. Each operation includes taking the instruction and the numbers to be operated upon from the store and returning the result to the store. For processing television signals it is necessary to accept input data at the rate of about $10^7$ numbers per second and a single television process may well require several arithmetical operations to be performed on each number.

Although general-purpose computers are too slow, the required rate of computation could be achieved by the use of special-purpose equipment, although at the time of writing the cost would be rather high. The required speed would be achieved by a process based upon the concept described in Section 2.1. in which a separate circuit is provided for each operation to be carried out on a given sample. A number of samples would therefore be undergoing processing simultaneously. These mass-production methods can be adopted because television signal processing does not require the essential characteristic of a general-purpose digital computer: the ability to examine the result of one arithmetic operation in order to determine which instruction is to be obeyed next. In signal processing, the same instruction is required to be carried out many times on a sequence of numbers representing successive samples.

### 3.2. Functions

A gamma corrector provides the best known example of a circuit, used in television, which operates upon a function of a single variable. When handling analogue signals, such a function may be operated upon by means of a non-linear circuit but it is difficult to obtain stability and reliability because non-linearity is usually associated with physical phenomena varying with temperature (e.g. the properties of semiconductors). An alternative approach which is coming into increasing use is to represent the function by a series of segments of straight lines.

When using a digital method, the simplest procedure would be to use a store containing one binary number for every input level to be distinguished. For example, for 8 bits (256 levels) it would be necessary to provide a store, with random access, containing 256 8-bit numbers. An ordinary computer store is not fast enough for this purpose but it is believed that the required speed could be obtained without undue difficulty by using a permanent 'read only' store. One such form of store might have 256 binary numbers recorded in the form of small metallic patches on a printed card; this card would be changed to change the function.

In most cases it would not be required to change the form of the function during operation but if it were it would be possible to envisage a store having the facility of modifying the stored numbers at a relatively slow rate.

### 3.3. Addition and Subtraction

Addition and subtraction are virtually the same operation since only a very simple operation is required to reverse the sign of a number. The operation of a fast parallel adder is illustrated in symbolic form in Fig. 9.

The eight small boxes indicate eight identical adder stages. Each of these deals with one bit only, for example stage number 5 could be regarded as representing the number $2^{-5} = {}^{1}/32$. Each adder stage has three inputs representing the appropriate bit of each of the two numbers to be added together with a 'carry' bit coming from the previous stage. Each stage has two outputs representing the appropriate bit of the result and the carry bit going on to the next stage. For mass-production operation the separate bits of the numbers to be added would not be arranged to arrive at the appropriate adder stages simultaneously and, as can be seen from Fig. 9, it would be preferable to arrange that the least significant bits reach the adder stage first.

In Fig. 9 the input and output lines are, for the sake of simplicity, supposed to be uniform transmission lines along which the groups of bit pulses representing successive samples are spaced out evenly, although in fact it would be more convenient to provide any required delays by the use of artificial delay lines or shift registers. Each arrow represents the position and direction of travel of the pulse representing one particular bit of one particular group. Successive groups are indicated by the letters A to J but for clarity only groups A, F, G and J are shown in the figure. It will be seen that the lines of bits representing successive samples impinge on the adder like waves striking a beach obliquely. The carry corresponding to each group traverses the adder chain so that at each stage it arrives approximately in synchronism with the corresponding bit from each of the numbers to be added; according to the design of adder, some departures from synchronism of the bits arriving at each stage may be required. In the example shown in the figure, each adder stage would be performing its contribution to the operation of addition at sampling rate - i.e. about 13 million operations per second. Moreover, all the stages would be occupied simultaneously so that different parts of the addition operation would be in progress simultaneously on eight successive samples.

Although the numbers to be added have been shown as having only eight bits, the sum requires nine bits. The least significant bit (the output from stage number 8) might either be carried through to further operations in order to avoid rounding-off errors or be discarded.

Adders of more than adequate capacity are now being produced on a single silicon chip and, although they are still rather expensive and slightly too slow for the purposes under consideration, the price and speed are improving all the time.

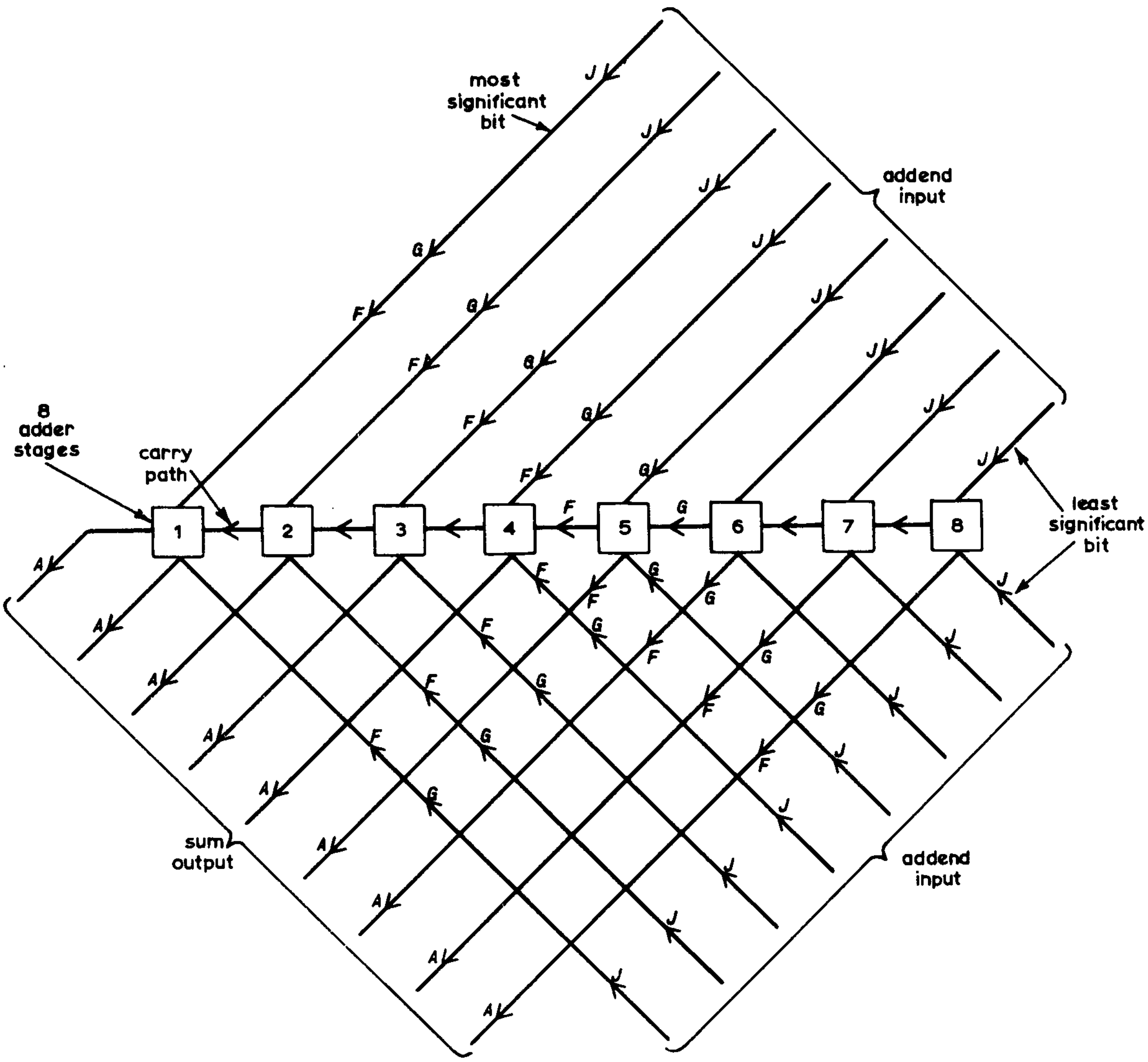


*Fig. 9 - Addition*

### 3.4. Multiplication

In a general-purpose digital computer, multiplication is performed by successively adding shifted versions of the multiplicand, each shifted version corresponding to each '1' in the multiplier. All these additions take place in the same adder, which is set to zero at the commencement. This procedure would be too slow for use in the processing of television signals, but sufficient speed could be obtained by using a separate adder, corresponding to a distinct station on a 'multiplying' production line, for adding-in each displaced version of the multiplicand. Arrangements would be made to inhibit this addition for those displaced versions corresponding to zeros in the multiplier.

An alternative procedure would be to take the logarithms of the numbers to be multiplied, add them together, and then form the exponential function or antilogarithm. The logarithm and exponential would be obtained by a process such as that described in Section 3.2.

### 3.5. Division

Division may be required for processing colour signals since chromaticity (which defines colour without regard to luminance) is determined by ratios of amplitudes of separation signals. Division could be performed by setting up a production line similar to that described above for multiplication. In this case all possible shifted versions of the divisor would be either added or subtracted. The choice between addition or subtraction (which would be accompanied by the addition or subtraction of unity in the appropriate position of the quotient) would be determined by the sign of the remainder existing after the previous operation.

Alternatively, and possibly more simply, division could be performed by subtracting logarithms and forming the exponential function of the result.

### 3.6. Storage

For the 625/50 television system, information is handled at $10^8$ bits per second (assuming $13 \times 10^6$ samples per second and 8 bits per sample). A scanning line requires about 6,500 bits and a field $2 \times 10^6$ bits, assuming that advantage is not taken of blanking intervals to effect economies.

Magnetic cores are still used for the main store in most computers, although it is likely that cheaper alternatives will be developed; the store of a typical medium-sized computer holds about 8,000 words, i.e. $3 \times 10^5$ bits. The cycle time, that is the time required to read (destructively) one word from the store and re-write it *in the same location* is typically 2 $\mu$s.

Thin magnetic films are coming into use for faster stores, but these are more expensive in terms of cost per bit, and are usually of smaller capacity. They are sometimes used as auxiliary fast stores in large computers; a typical store of this kind would hold 40,000 bits and have a cycle time of 300 ns.

For the fastest, but most expensive stores (in terms of cost per bit), a separate active circuit is used for each bit. On the other hand, other forms of active store can be used to produce an auxiliary fast store which is cheaper than a thin film store; a store of this kind holding 1600 bits can be manufactured as a single integrated circuit with a cycle time of about 400 ns.

It is clear that the total storage capacity required for television presents no great problem unless complete fields have to be accommodated. It is quite practicable to accommodate a few fields in core stores but the cost is at present rather high, though diminishing as time goes on.

In order to obtain a sufficiently high rate of transfer of information to and from a conventional core store, two procedures are available. In the first place, the store may be sub-divided into a number of sections, successive picture elements being allotted to the sections in cyclic order (as playing-cards are dealt to a number of players). The alternative is to write information into the main store or read it from the store in bulk, that is to say in long words each containing 200 or more bits describing 25 or more samples. It might be best to employ both these methods. Long words read from the main store would be transferred to a small faster store, which might take the form of a set of shift registers, for breaking down into groups of bits describing individual samples. Fast shift registers are available in integrated circuit form.

Use of stores of the type outlined above would give a certain amount of freedom in the order in which groups of bits were read from the store; it would, for example, be possible to omit groups of bits corresponding to certain picture elements along each line. Nevertheless, completely random access to a store containing whole fields of information would hardly be practicable.

Alternative forms of store are possible when all that is required is a delay. Magnetic drums are still being installed in computers so as to provide a backing store having a lower cost per bit than a core store. A drum can provide a capacity of up

to $2 \times 10^6$ bits and can give a delay of up to one field.

For a short delay not exceeding a few microseconds, a set of shift registers, one for each of the 8 bits of a number may be used. A variable delay - for example to provide timing correction for the information being read from a drum - could be provided by a set of shift registers with a facility to read the information at any point.

Ultrasonic delays are still used for digital signals and may have advantages for certain purposes although these advantages are likely to diminish as core stores, thin films, etc. become cheaper.

### 3.7. Filtering and Equalizing

Filtering and equalizing, including horizontal aperture correction and after-glow correction, may be performed by convolution. The number, describing the brightness of each picture element, is replaced by the weighted sum of contributions from a set of adjacent picture elements. This kind of operation appears very expensive to perform on digital signals and is probably one of the operations least worthwhile performing in this way. One way of performing it is to feed the incoming information into a set of shift registers, taking outputs from each stage of these registers to the multipliers and adders required to form the weighted sum.

Vertical aperture correction is similar in principle except that the samples are required to be separated, in time, by multiples of the line-scan period. Thin film stores might well prove suitable for storage assuming that it is required to perform correction only within a single field, rather than to use a field delay to obtain access to adjacent lines in a picture.

### 3.8. Standards conversion

A line-store standards converter requires a store sufficient for one scanning line; information is written into this store at a rate appropriate to the incoming scanning standard and read out of it at a rate appropriate to the outgoing television standard. Thin-film stores may well prove suitable for this purpose. For interpolation, access is required to corresponding picture elements on a few adjacent lines; again a thin-film store would be suitable unless it is required to have access to adjacent lines in the picture in which case either a large core store or a drum would be required (unless and until the cost of thin-film stores comes down significantly). The formation of the interpolated number from the numbers representing elements on successive lines would be effected by performing multiplications and additions.

Consideration of 'line-store' standards converters[8], which change the number of scanning lines without forming an intermediate optical image, began in the BBC in 1960, and, following preliminary experiments, development began in 1962. At that time serious consideration was given to the possibility of performing the conversion digitally, but it did not seem practicable, using the digital techniques then available, to achieve a digital standards converter by the delivery date required (early 1964). The converters that were developed stored information in analogue form, and certain disadvantages have resulted; in particular, vertical striations are evident in the converted picture.

In view of the picture impairment introduced by present-day converters, it may be considered desirable that an entirely new generation of line-store standards converters be developed; it would be practicable and desirable to develop digital converters for this purpose.

Field-store standards converters are based on more recent inventions.[9,10,11] Their role is to change both the number of scanning lines per field and the number of fields per second; to do this it is necessary to store between one and three complete fields of the television waveform. When this development began in 1965 use of digital techniques was again considered. It was already realized that these techniques had advanced sufficiently for their application to line-store converters, but it was nevertheless decided to use analogue methods for field conversion because the cost of digital storage was considered to be too high. It is confidently expected that this last disadvantage will have been overcome within a few years and that it will then be both practicable and economical to perform all standards conversion by digital means.

Standards conversion is sometimes employed as a means of achieving synchronism between picture sources. A simplified form of field-store standards converter, which need not incorporate interpolation, would be ideal for this purpose.[12] Such a device may well prove essential when transcoding SECAM signals to PAL. The SECAM system permits a line-frequency tolerance of one part in $10^3$ whilst the PAL system requires a much tighter tolerance; typical figures are one part in $10^6$ (Standards B and G) and two parts in $10^7$ (Standard I).

### 3.9. Magnetic Recording

Enormous advantages would result if magnetic recording could be digital. Programmes could be

dubbed from one tape to another many times, both for editing and for distribution, without loss of picture quality and the correction of timing would be easy to accomplish. Unfortunately, existing recording tape does not enable information to be stored at a density exceeding $3 \times 10^8$ bits per $m^2$.[13] Thus recording tape would have to be used at a rate of 0·3 $m^2/s$ whereas existing professional video tape recorders use tape at only ·014 $m^2/s$ (2 in. wide tape at 15 in./s). It might at first sight appear that the storage of information in digital form must be highly inefficient in comparison with the f.m. modulation system used for video tape recording, but account should be taken of the fact that existing television recording techniques introduce a significant degradation, which is equivalent to a considerable loss of information.

Work is in progress in many organizations to increase the packing density of digital information on magnetic recording media.[14] It is likely that the high densities required for television will be achieved as a result of the use of continuous metallic films rather than of the magnetic oxide used at present.

### 3.10. Telerecording

Film telerecording offers two advantages over magnetic recording. In the first place it offers a cheap and convenient method of duplicating programmes for export. Secondly, it avoids the need for standards conversion since, when replaying the recording in a telecine, it is not necessary to enquire what television scanning was used when the recording was made. If digital methods came into general use it might prove desirable to record the television waveform on film in a digital form since this would realize the first advantage referred to above - ease of duplication - although it would no longer obviate the need for standards conversion. Colour signals could, of course, be recorded on monochrome film by digital means.

It is believed that the area of film required per second, assuming a packing density compatible with contact printing,[15] would be of the same order of magnitude as that for conventional 16 mm film. This point does, however, merit further study with a view to determining the greatest practicable packing density.

### 3.11. Programme Distribution

It is believed both in the G.P.O. and in the telecommunications industry that the trend towards the adoption of pulse-code modulation for telephone traffic will continue. It therefore seems likely that the G.P.O. will consider its applications to television circuits.

## 4. CONCLUSIONS

It is believed that the trend towards digital methods throughout the whole electronics industry will continue and that we ought to be prepared to reap the benefits that this can confer and to apply them to television broadcasting. The introduction of digital methods does, however, present a difficulty which is comparable with that which, at one time, was presented by the introduction of transistors. To introduce a new method throughout any system may seem too ambitious a project, whereas its piecemeal introduction is apt to be uneconomic. In other words it is difficult to make a start.

It is thought that the most promising field for the introduction of digital methods will be to large pieces of equipment in which the use of analogue methods are likely to introduce picture impairments. It is probable that standards converters will prove a suitable field for digital methods if and when second-generation line-store and field-store converters are required.

The effort directed to digital computing techniques throughout the world is enormous in comparison with that available for research and development in the field of broadcasting. It does not therefore appear desirable to attempt to compete with this work in any way. Research Department effort ought therefore to be directed into problems which are peculiar to television and to the adaptation to television of techniques developed elsewhere.

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